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Climate-Resilient Urban Design from a Biomimicry-Arcology Perspective

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Abstract – Global climate action initiatives have focussed on either climate mitigation or adaptation in the decarbonisation agenda. The impact of urbanisation is generally overlooked. Urban development alters the environment, including climate, in multiple ways. Therefore, climate actions are unlikely to succeed, even if its goals are achieved, largely because the current paradigm promotes expansion at the expense of nature. This paper presents an alternative perspective on urban design with respect to climate resiliency. It draws primarily from the thoughts that underpin Arcology and Biomimicry from a complex, evolving Earth systems paradigm. It argues that urban development must shift from 2-dimensional gigantism to a compact 3-dimensional form. It further posits that the structure should facilitate greater exchanges, drawing together complementary elements in economy, industry and society, and services into the same structure. Hyper-structures, multi-functional infrastructures, and systems are required to drive the transition towards a more efficient, low-impact urbanisation paradigm that frees the land for nature to recolonize. Biomimicry provides suitable models and guides through species that thrive as well as biomes that have developed in the range of environmental and climatic regions on the planet. A viable approach would be to build on existing transport infrastructure.

Keywords: *arcology, biomimicry, climate, paradigm, urban design*

I. INTRODUCTION

The Climate Crisis refers to the emergent situation of heightened risks from climate-related hazards and disasters (Lavell, 2012). There is increasing frequency of 'extreme weather', ranging from heatwave, drought, tornadoes as well as heavy snowfall, blizzards, high rainfall, floods and cyclones. They cause disasters when they intersect with human elements, particularly, in areas of high population or structures of high value. UN Habitat (n.d.) identified as a challenge in the coming decades the need to deal with "hundreds of millions of people in urban areas [that] are likely to be affected by rising sea levels, increased precipitation, inland floods, more frequent and stronger cyclones and storms, and periods of more extreme heat and cold". The first target in the United Nations' Sustainable Development Goals on Climate Action (SDG13) is to "strengthen resilience and adaptive capacity to climate-related hazards and natural disasters in all countries". Although urban areas are vulnerable to the climate crisis, it is a significant contributor, accounting for 71-76% of CO_2 emissions from global energy use (UN

Habitat, n.d.). Furthermore, urban development affects climate in more ways than input of greenhouse gases. The relationship between urbanisation and the climate crisis is a mutually affecting one (While and Whitehead, 2013).

Urbanisation incrementally displaces nature with built structures, altering landcover and interfering with natural environmental flows in the process (Slaymaker et al., 2009). Urban areas emit higher amount of heat, in addition to CO_2 from vehicles powered by fossil fuels, which the latter has the capacity to retain heat in the atmosphere. As the scale of urban development increases, its impact on the natural environment and environmental systems becomes more apparent. This includes changes in the pattern and characteristics of atmospheric and hydrological circulations, which are major controls of regional climate. Within the urban space, impermeable artificial surfaces increase storm runoff, which is accentuated by the loss of interception of precipitation afforded by vegetation cover, resulting in more frequent and or intense flash floods. The loss natural vegetation also removes natural buffer against strong winds and heat build-up, as well as reduce the carbon sequestration capacity of the environment. Therefore, even in low density urban area, the effect of climate hazards is amplified due to the physical properties of urban areas. Large sprawling cities and conurbations have considerably greater effects on regional climate, and if inadequately managed, are also more vulnerable to climate risks. Changes in regional climate have a global effect due to teleconnections within the fluid atmosphere (NOAA, n.d.).

The fight against climate change adopted by nations and industry, which are primarily guided by deliberations and strategies adopted at the United Nation's climate conferences, could be grouped into two main approaches: (a) mitigation through reduction of CO_2 emission, and (b) adaptation to climate hazards. The former has garnered a disproportionate support and attention from political and industry leaders as well as society in general. This has persisted in the recently launched work programme on the global goal of adaption during COP26 in Glasgow in November, 2021, where only 20-25% of funds were committed to climate adaptation (United Nations Climate Change, n.d.). It is unclear why this is the case as the effects of climate change is most destructive in high-density urban areas, particularly those that lack the necessary infrastructures and mechanisms to cope with and recover from such disasters. This is however a less significant problem. Excluding the contribution of urbanisation, notably systematic displacement of natural landcover, in addressing the climate crisis is a major problem, because it retains a large gap in the approach to address the climate crisis. This has real and deleterious consequences because, given the antagonistic relationship between urbanisation under the current development paradigm and nature, many of the climate risks would remain, even if the program to reduce CO_2 emission were successful.

This paper aims to present an alternative perspective on urbanisation and the climate crisis. It contrasts starkly with the current dominant view that concerted international, cross-sectoral, public-private and grassroot efforts is needed to usher in the decarbonisation agenda with heightened urgency. An agenda characterised by a switch to renewable energy sources and electric vehicles (EV), and often side-tracked by unrelated, but associated issues under ESG (environment, social justice and corporate governance) requirements. This paper aims to show that it would be prudent to examine the paradigm of urban development and address climate resilient design from an alternative perspective. The paper draws from three related schools of thought, namely (a) arcology, (b) biomimicry and (c) complex, evolving Earth system. It will use examples in Brunei and the region for the purpose of illustration. The paper will conclude with a number of design perspectives, which it could strengthen resilience of urban areas to the climate crisis.

II. METHODOLOGY

In the interest of full disclosure, the author is not an architect by training or profession. The author's background is in Earth science and environmental modelling, with nearly three decades of experience in the arena of geography, environment and development studies. In standard modelling, the paradigm used is consider in the conceptualisation phase. As this study involves participation by living elements (people and other living organisms), the most appropriate paradigm would be one of a living system; an organismic rather than a mechanistic one (Capra, 1997), where life, the sum total of all organic life on Earth, is an active component, capable of co-creating the Biosphere (Vernadsky, 1988) and the environment since life appeared on Earth four billion years ago (lovelock, 1988; Margulis, 1998). This planet and its surface condition, including the atmosphere in which climate is experienced

and where humankind interacts with nature, is a complex system, capable of responding to change, driven by the tending to restore equilibrium. The self-organising process extends to conscious decision-making and interaction-communication among people in the production of society, culture, economy, laws, and the entire complex mesh of interconnected human systems (Maturana and Varela, 1980).

The rationale for taking a perspective from a combination of Arcology (Soleri, 1969) and Biomimicry (Benysus, 1997) is explained as follows. Soleri developed Arcology to address urban sprawl, which he identified as a major component in urban development and but one that is unsustainable, due to its wasteful and high resource-demand. As explained at the outset of this paper, this has a significant contribution to the climate crisis. Biomimicry posits that sustainable solutions exists in Nature, embedded within the structures and or life strategies of organisms in the variety of environment types. This includes harsh conditions that are hostile to life. Yet, a community of organisms has adapted to thrive. There are therefore organisms and biomes that contain solutions to the range of extreme weather hazards associated with climate change. The central tenets of these schools of thought are further elaborated below in sections A and B. The justification of using examples from Brunei Darussalam (for brevity, "Brunei") is to provide illustrations of points raised or designs proposed. It is also chosen due to the author's familiarity with the environment and development context. Section C provides further details on Brunei to establish the context for illustration in this paper. Figure 1 is a schematic diagram of the research methodology. In effect, it combines three schools of thoughts, which share an overlapping basis of ecological thinking, to address the aim of identify design urbans (features, principles or strategies) to enhance resiliency in the context of the climate crisis.

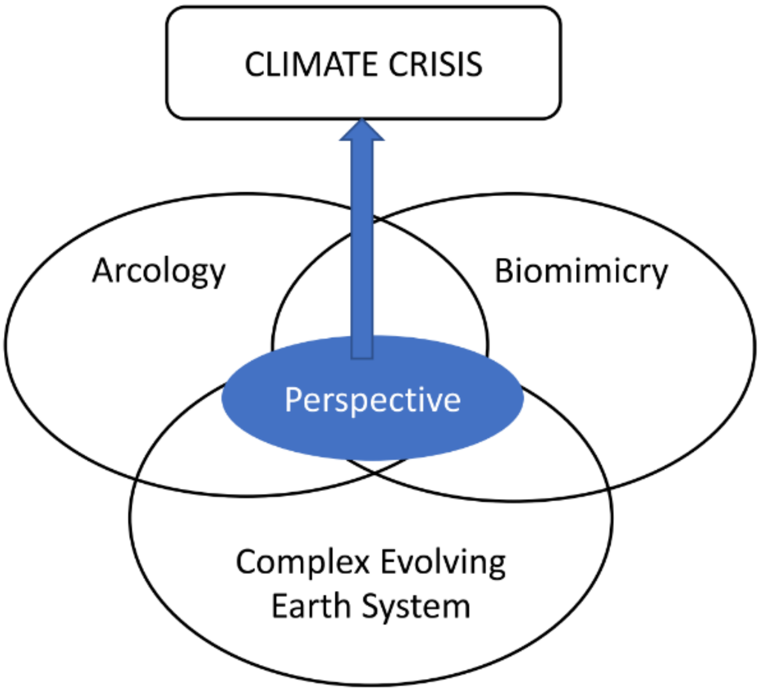


Fig. 1. Research Approach

A. Arcology

Paolo Soleri developed Arcology in response the grotesque urban sprawl developing in the United States of America, which he attributed to a development paradigm based on the suburban logistical networks (Soleri, 1969; Soleri et al., 2011). Arcology, architecture founded on an ecological, evolving Earth, was a radical but visionary concept in the 1970s. However, it makes good sense and is highly relevant at the dawn of the 21st century (Johnson, 2010; McCullough, 2012). Soleri related urban sprawls to the invention of the automobile with air-conditioning, which allows people to live increasingly further from their routine destinations. This established a development paradigm that is ever-expanding, a sclerotic gigantism, that displaces nature incrementally with development. It is wasteful, because consumes large amounts of resources (and generating waste, C)2 in particular) and destroys nature in

its path. Nevertheless, denizens go about their daily lives, similarly expending large amount of energy (fossil fuel) in commuting. Although this transformation of the natural landcover have significant impacts on environmental processes and cycles, Soleri was more concerned with the loss of vital energy and time spent on the road, often stuck in traffic jams. Sprawling development saps the life out of the city, and the vitality of its denizens. This has real cumulative effects on quality of life, relationships, health, personal development, opportunities, so on and so forth.

The central tenet of arcology is miniaturisation. The imperative of Nature appears to be: miniaturise or die! (Soleri, 1969; Johnson, 2010; Imperiale, n.d.). In nature, the structure of organisms, biomes and ecosystems becomes more connected and compact as they develop towards maturity. Miniaturisation refers to the shortening of travel-time or the duration separating interaction and exchange. Miniaturisation is necessary as systems and organisms grow in size, because it reduces energy and resources lost in transmission. In nature, this is achieved through densification of connecting pathways, whether in the form of blood vessels in a living organism or communication channels in an urban complex. Soleri sees the processes of miniaturisation, complexification and duration as a single process of increasing efficiency of the organism or system. He used Man as the model of a vibrant and vital city in his first publication, The City in the Image of Man, because of the human form and faculties, and its capacity for cognition, reflexivity, reasoning, planning and managing its existence. Urban sprawl is antithetical to the development process and structure of organisms and ecosystems because its trajectory is towards increasing resource consumption (and demand), waste and wastage, thus, increasing inefficiency.

A miniaturising structure would be compact and 3-dimensional. An arcology is effectively an imploding, as opposed to sprawling, development, which spreads out 2-dimensionally over the ground. A hyper-structure would be required to guide this development process, similarly to how skeleton and tree architecture give form to organisms and forests. These structures are however multi-functional, a necessary condition for efficiency, miniaturisation and enhanced interaction. A hyper-structure therefore integrates different sets and systems of infrastructures current spread out horizontally into a single multi-functional 3-dimensional structure that guides and supports 3-dimensional urban development, facilitating the growth of the city upwards and outwards. This is akin to reorganising the current infrastructure and land uses in 3-dimensional space, meaning production of food, industries, services and settlement would be within the arcology, i.e., they are not produced elsewhere on the Earth and transported to the city; the arcology would be largely self-contained. The manner of reorganisation would close the distance-time pathways between supply and demand of services and products, a ubiquitous feature of ecosystems, sometimes referred to as closing the loop. Additionally, as ecosystems have the capacity and tendency for self-organisation, organic processes must be considered and accommodated in the design of hyper-structures. As Soleri conceived of an arcology as a living entity, the city and its physical hyper-structure would growth concomitantly with its population.

Finally, for Soleri, architecture must be coherent with the environment, flowing with it rather than presenting a barrier to natural dynamics. Soleri's emphasis on congruence with the natural environment widen the scope of arcology beyond individual building complex to the city as a whole. It is therefore an integration or application of architecture with/in development planning. Soleri used a metaphor of orchids in the forest to differentiate between the 'form givers' that produces orchids (individual building complex) and the 'forest architects' that provide shelter to many (McCullough, 2012). In Soleri's view, architecture at its best strives toward increasing coherence and transcendence, which implies a built environment geared towards cooperation, tolerance, benevolence and beauty (ibid. p.19). Piece-meal urban development would preserve the isolated culture of suburban living created under the current paradigm, where individual live in enclosed private properties and commuting to various destination each day before returning to the same enclosed unit ('home', or 'hermitage' in Soleri's view). According to Soleri, "our cities should be compact, cooperative, multifunctional, waste-minimising environments that concentrate creative energies instead of disintegrating and degrading them in the energy sink of sprawl, gigantism, auto-isolation, auto-enclosure, 'hermitage' culture, inequality, bigotry, and squalor, while also leaving as much of the natural world as possible free from suburban and exurban encroachment" (McCullough, 2012: p. 21-22).

B. Biomimicry

The publication of Biomimicry: Innovation inspired by Nature (Benysus, 1997) has stimulated much interest and spawned a professional consultancy service (Biomimicry Guild; Biomimicry 3.8), an education platform (Biomimicry Institute) and an online database of biomimetic research (Ask Nature). Benysus posited that Nature is model, measure and mentor for sustainable solutions. This is based on the fact that life has existed on Earth for 3.8 billion years, surviving several cataclysmic events, and in the process, become more diverse in species, denser in biomass (higher population) and more resilient to environmental variability. The premise is that, if life has survived for such a long time on a planet that has undergone drastic transformation, then it must have evolved (or innovated) structures and strategies to thrive in the gamut of environmental types. The objective of biomimicry is therefore to look for sustainable solutions that are embedded within the structure, design and life strategies of organisms that are most successful; Benysus refer to them as ‘genius of place’. Although the application of biomimicry (or its synonyms, bionics or biomimetics) in industrial design is relatively recent, traditional human communities across the world have learned from nature since the earliest civilisation to improve their survival potential. They include ways and means of hunting, building shelter, processing materials, and protection against harm. They have also been incorporated into culture through dances and motifs. In a study of the historic water-based settlement, formerly the capital city of the Brunei Sultanate, Yong (2021) related the design of dwelling, morphology of the settlement complex and development of traditional culture to unconscious mimicry of the surrounding estuarine environment. Similarly, Chen (2017) elucidated strong congruence between the structure and morphology of Daiwei village in China with the mimicry of Nature.

Biomimicry has been applied in various fields over the past 2-3 decades. This includes architecture (Knippers et al., 2016; and Pawlyn, 2016). Apart from the authors cited, other notable examples architects that employs biomimicry include Jacques Herzog and Pierre de Meuron (Beijing National Stadium), Chris Bosse and Rob Leslie-Carter (Beijing Aquatic Centre), Norman Foster (The Gherkin, London), Mick Pearce (Eastgate, Zimbabwe), and Michael Wilford (Esplanade, Singapore) (Rethinking the Future, n.d.). However, as this paper focuses on urbanisation rather than architecture per se, it will refer mainly to the methodology used by Benysus, which is the Genius of Place or Biome approach (Biomimicry 3.8, n.d.). It involves identifying the species that thrive in the area of interest in order as a means to identify suitable models for mimicry in innovation solutions. With respect to climate adaptation, life adapted in different ways to the range of environments on the Earth’s surface, from extremely hot and dry to extremely cold, and regions that are affected by cyclones or tornadoes seasonally. These natural regions or biomes are communities of organism that have adapted best to the environment in which they live. There are therefore geniuses to mimic for every type of environment and contingency for climate hazards. ‘Nature as mentor’ (Benysus, 1997) implies that we must respect nature and pay attention to what it is telling us. This contrasts with modern development paradigm, which subdue, displace and replace nature with built systems simply because it is capable of doing so to achieve its objectives, without considering interconnections with the planetary system.

C. Brunei Darussalam

Brunei is a small country (area 5,765 km^2) located along the northwest coast of Borneo. The country is surrounded on its landward side by the Malaysian state of Sarawak, which also separates the country into two parts. The Capital city, Bandar Seri Begawan (BSB), is located on the western part of the country, together with the majority of the nation’s population. It lies on the north bank of the Sungai Brunei estuary at the site of the historic water-based city, known today as Kampong Ayer, in the Brunei-Muara District, the smallest (area 571 km^2) of the country’s four districts. Brunei lies within 4-5°N of the equator. It experiences a tropical monsoon maritime climate, due to its proximity to the South China Sea. The seasonal (monsoon) effects are controlled by the fluctuation of the ITCZ (Inter-Tropical Convergence Zone) to the north and south of the country during the northern hemisphere summer and winter respectively. The main monsoonal characteristic is the change in prevailing wind: north-easterly during the ‘winter months’ and south-westerly during ‘summer’; the latter is due to diversion of the southeast trade wind as it flows across the equator. The climate is characterised by high and intense rainfalls with strong spatial-temporal variability, with November to January typically being much wetter and March often drier than the rest of the year. Seasonal variation in ambient air temperature is minor. Brunei’s climate is significantly affected by the El Nino Southern Oscillation (ENSO) in the equatorial

Pacific Ocean due to teleconnection, becoming abnormally drier or wetter during El Nino and La Nina events respectively.

Satellite imagery and old topographic maps reveal that Brunei was largely forests as recent as fifty years ago. The centre of the Brunei sultanate (modern-day Kampong Ayer) was located in the Sungai Brunei estuary since the 15th century. The transition to land occurred during the early part of the 20th Century after Brunei had accepted to become a British protectorate. The British initiated a transition and migration programme to land, establishing the first town and Capital, Brunei Town (BT, see Fig.2), on the mudflats north of Kampong Ayer. The discovery of oil and gas fields in the post-WWII global economic boom period provided Brunei with the necessary funds to modernise and to strive towards independence as nation state, which it achieved on 1st January 1984. Development occurred at frantic pace, and urbanisation quickly displaced areas of rainforest, filled in swamps and cut up hills. Between 1981and 2011, the urban area in the Brunei-Muara District expanded more than two-fold from 74 km^2 to 170 km^2, accounting for 30% of the district's land area (Ng, 2020). The sprawling nature of urban development is driven largely by landuse policy adopted in the first National Landuse Masterplan (1986), which promotes decentralisation from BT (ibid.), which was renamed BSB in 1970 after the late Sultan Omar Ali Saifuddien III, the 28th Sultan and arguably the architect of modern Brunei. Figure 2 shows the extent of urbanisation by 1991, captured on June 14 by the Landsat 5 satellite.

A second national master plan in 2005 called for infill and consolidation. This led to the move to expand the administrative boundary of BSB from 12.87 km^2 to 100.36 km^2 (Ng, 2020). Although urban development is planned and regulated by the Department of Town and Country Planning (DTCP), its policy to exclude private land in development plans coupled with the long-delays that is characteristic of bureaucracies in general, resulted in high degree of organic growth along major roads, which subsequently branch out due to development pressures led by private property owners. DES-Department of Statistics Government of Brunei Darussalam (2016) advise the low population (114,231 in 1981 census to 279,921 in 2011) of urban development in the Brunei-Muara District is characterised by low-density sprawl, even though population density more than doubled from 200 to 490 persons per square kilometre over the 1981-2011 period (ibid.). Furthermore, as the expanded BSB encompasses the main valley of Sungai Kedayan, one of the three major river systems within the district, flash floods have become a frequent occurrence, particularly when the winter monsoon coincided with a La Nina event. Based on local and personal knowledge, the occurrence of flash floods is largely due to property development outpacing infrastructure as well as inadequate management of drainage system, which are continually being clogged-up at numerous sections due to a combination of solid materials falling in and getting stuck, sedimentation associated with storm runoff and colonisation by natural vegetation. Although flood levels are relatively shallow (generally knee deep) due to small catchment area, they nevertheless cause significant disruption to life and economy, destruction of property and infrastructure, and distress to the affected individuals. Climate change is expected to exacerbate the situation, given that the main channels, Sungai Kedayan and Sungai Brunei are estuaries, meaning, they are connected to the sea, and therefore are susceptible to sea level rise.

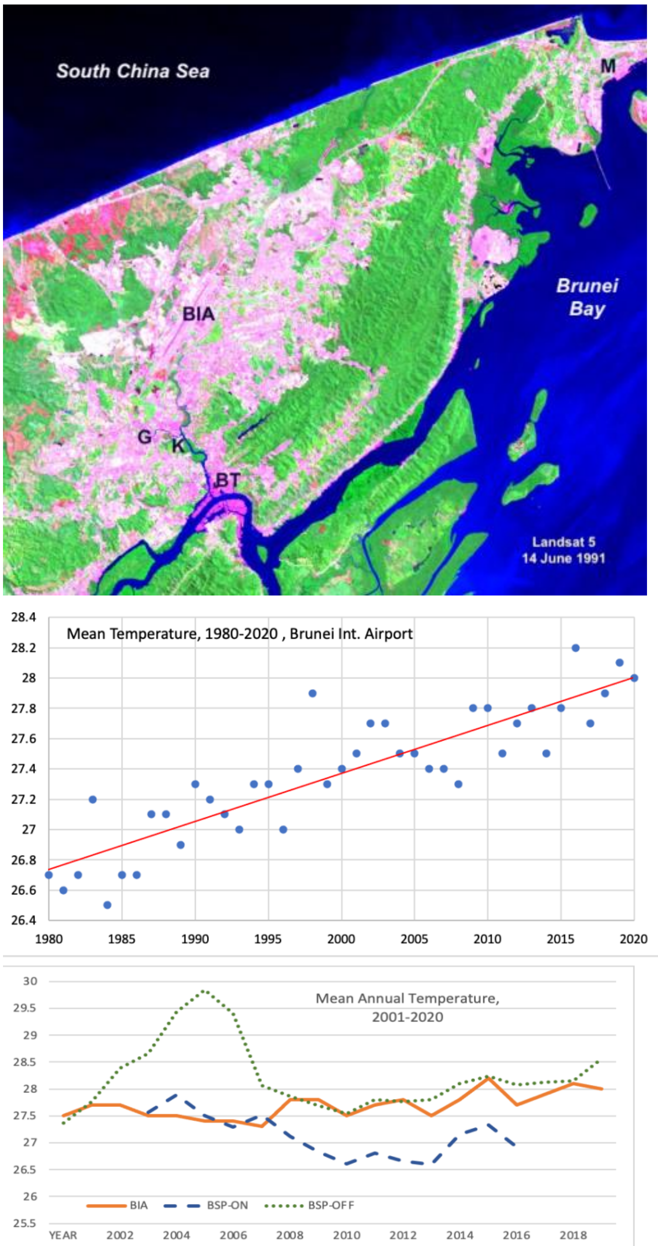
III. DISCUSSION

The aim of this paper is to offer an alternative perspective on urban development and design in the context of the current climate crisis. This paper does not emphasize or discuss Brunei Darussalam. However, for the purpose of illustration, it will use Brunei as a case example simply to provide a context in discussion. However, Brunei's characteristics as a small coastal state and an oil-producing nation are also particularly relevant. The former meant that it is susceptible to sea-level rise, a major concern of climate change, while the latter is commonly associated with contribution to the climate crisis. Its modern development trajectory (rapid urbanisation resulting in sprawls and deforestation) is also suitable as reference in this paper. The discussion will be divided into five sections: (a) urbanisation and climate; (b) coherent approach to urban development; (c) the Urban Effect; (d) Hyper-structures and Genius of Biome; and (e) overcoming barriers.

A. Urbanisation and Climate Change

Climate change generally refers to rising ambient air temperatures over the long-term and an increase in weather hazards associated with greater climate variability (Lavell et al., 2012). The top table

in Figure 2 shows mean annual temperature derived from measurements made at the Brunei International Airport (BIA) since 1980. It clearly shows a rising trend with the linear trend line having a coefficient of determination (R-squared) of 0.79. Based on this trend, mean annual temperature is expected to be 28.9°C in the year 2050, compared with 26.4°C in 1980, i.e., an increase by 2.5°C. The lower table however reveals that this rising trend is not observed in two other areas in Brunei. The data from BSP (Brunei Shell Petroleum), which has long-term observation since operations began do not reveal any rising trend. BSP-ON is measured at the company's headwaters near the coast in Seria, in the Belait District, while BSP-OFF is measured on their offshore platform, approximately 40 km off the coast at the southern edge of the South China Sea. Meteorological and oceanographic (generally referred to as 'metocean') data are essential to safe operations in the oil industry. Although we were only able to obtain 13 years of data at the time of writing, the pattern is sufficiently revealing, showing slightly negative trend in contrast to the BIA data. The difference is due to context. BIA is located in an area that has undergone tremendous urbanisation (refer to the 1991 Landsat image, Fig.2) whereas BSP-ON is much less urbanised and experiences strong ameliorating effect from the South China Sea. BSP-OFF is not influence by variation in landcover as it is surrounded by the sea. Figure 2 suggests a correlation between rising ambient temperatures and landcover change, notably urbanisation. The administrative extent of BSB stretches from BT in the south to BIA to the north.



False-colour image of Brunei-Muara District:

- urban areas (pink);
- bare ground (red),
- forest (green);
- Water (blue).

Temperature pattern:

- (top) BIA;
- (bottom) BIA, BSP onshore and offshore.

Fig. 2. Urban Development and Temperature Pattern

The effects of urbanisation in Brunei have been limited to rising ambient temperatures and increased frequency of flash floods. Although there are signs of coastal erosion, the lack of environmental monitoring makes it difficult to establish if they are due to rising sea level or the effects of storms due to regional climate variability, such as ENSO and teleconnections with other regional scale atmosphere-ocean dynamics (NOAA, n.d.). However, as explained at the outset of this paper, urban development would alter natural dynamics, including climatic characteristics and patterns, because of the continual displacement and replacement of natural landcover and landform with artificial materials, which have strikingly different properties (Slaymaker et al., 2009; While and Whitehead, 2013). Notably, urban landcover and processes add heat in the form of long wavelength infrared radiation, as well as greenhouse gases, which retains heat in the lower atmosphere. This is the main process that produces greenhouse effect, which is the basis of the Global Warming theory. Changes in heat pattern over the surface of regions will alter circulation patterns of air and water, the degree of which depends on the scale of change ('environmental impact'). Environmental flows could convergence in some areas and become more intense, resulting in anomalous conditions (hot/cold and dry/ wet spells, and intense, powerful winds), which could have disastrous outcome when they intersect with vulnerable urban areas. Therefore, although urban development directly alters the physical environment, its impact could be felt further beyond due to its effect on environmental flows and changes in flow characteristics (While and Whitehead, 2013). This interconnection is a major concern in environmental impact assessment (EIA) and environmental management system (EMS), practices used to bring about sustainable development (WCED, 1997).

B. A coherent approach to Urban Development

Central to Soleri's arcology thesis is coherence between architecture and the natural world; the scope of architecture must go beyond individual buildings to the city as a whole, in Soleri's reference to 'forest architects' (MuCullough, 2012). This aligns with eco-engineering, eco-design and other environmental or 'eco' management or design concepts. Although it is vital to consider urban design at the building-local area level and continually update conventional definitions through reflective and abductive reasoning and conceptualisation (C ̧alıs ̧kan, 2012), Soleri stressed the importance to consider the architecture of the city and its development. The foundation of Arcology is congruence with the natural world, which Soleri recognised as one of increasing efficiency and frugality as organisms and ecosystems develop in size towards maturity. The current paradigm which has given rise to 'grotesque' sprawls, is antithetical to nature, constantly expanding and consuming energy and resources, at the expense of nature and life (including the vitality of human society). Gigantism is unsustainable, as it unnecessarily consumes and wastes large amounts of resources while simultaneously causing environmental condition and flows to alter drastically. The process and its deleterious impacts are obvious to logical analysis. Yet, although many recognise it, the process continues unabated due to current policies and practices, prompting Soleri to describe it as 'sclerotic' (Soleri et al., 2011).

Changing development paradigm is however easier said than done. A tremendous amount of money, effort and emotions (hopes and dreams) have been invested to develop urban infrastructure, public facilities, private enterprises and myriads of homes. A radical reformulation of the urban development paradigm is almost impossible. Biomimicry might help to elucidate the matter. Biomes develop in response to environmental, in particular climatic, conditions. Returning to Brunei and the region for illustration, the natural environment is that of a tropical evergreen rainforest. Using Janine's Benysus's genius of biome approach, the solution might lie in how a tropical rainforest develop. The climax (mature) rainforest is characterised by tall trees that open up a canopy of foliage at the top and is propped up by large buttress roots. As a forest, the interlocking canopy and root system create new layers, including those that eventually form within the space in between the canopy and forest floor. They contain structures that facilitate or serve a wide range of functions for organisms and ecosystems that have established in the different layers, as well as for the forest a whole. The rainforest is a community, habitat and ecosystem at the same time. It is self-sustaining because it draws energy and material resources directly from its surrounding, establishing a dynamic equilibrium with the environment and environmental flows. However, the rainforest does not form from the different species growing together at the time. Instead, it develops in a series of successions, each stage preparing the conditions for the next. The different stages of the rainforest do not resemble the climax forest. Indeed, they differ distinctly in characteristic from one stage to the next.

A genius-of-biome approach would involve identifying the structure and life/survival strategy of organisms in the biome and the biome as a whole. Rainforest exists in a region of high and intense rainfall. While the warm and humid conditions are conducive to life, hence the high biomass and biodiversity, the environmental processes actively leach nutrients from soil layers as well as erode the land, causing the land to be infertile and cut up by numerous gullies, ravines and valleys. The large amount of water in the environment also give rise to water-logged and anoxic areas, which are also not conducive to life. Yet, certain species have adapted and thrived in these apparently inhospitable areas. They however tend to be short-lived or have seasonal or annual life spans. As they live and die in the area, they slowly transformed the environment, making it more habitable for larger, more complex species with longer life-spans to co-exist in the area. Each succession creates the necessary condition for the next stage, increasing the complexity and sustainability of the ecosystem in the process, until the climax forest emerges after a considerable period of development. When compared with forest succession, the 2-dimensional urban spawl resemble the early stages of the rainforest. Figure 3 shows a suggested parallel between natural succession and evolution of urban development. From an organismic perspective, humankind is but one specie in the living, evolving system that form the Biosphere. It is therefore a natural response for humankind to recognise impacts caused by its action and seek to remedy unsustainable practices and trends, because we share the same innate capability to work towards attaining equilibrium.

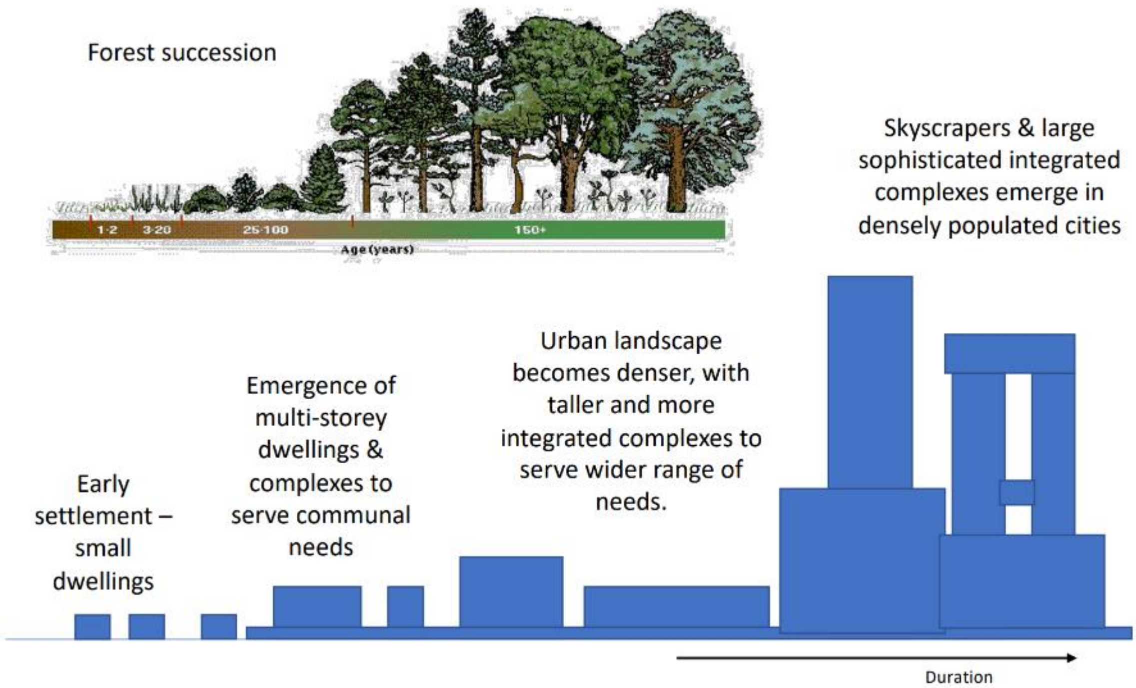


Fig. 3. Parallel between Forest Succession and Urban Development

Across the globe, there are regions at varying stage of urban evolution. Brunei, as a young nation, is very much at its infancy and therefore development is characterised by low density sprawl. In advanced industrialised nations, there are eco-architects, eco-engineers, eco-city developers and a host of others working towards driving a transition towards a more ecological future. This was the outcome of an acrimonious process between industry, society and political leaders, which herald an era of ecological modernisation (Hajer, 2005). This paper hopes to relate the current movements in eco-architecture, eco-city and eco-design in general with a process that should be recognised as characteristic of the living, evolving system that has shaped the Biosphere and of which, humankind is an integral part. The corollary would be to add momentum to this shift away from the prevailing unsustainable development paradigm and be mindful that the process would occur in stages, through a series of succession. This contrasts with mechanistic thinking under the prevailing paradigm where development occur 'instantaneously' (built within a relatively short timeframe) and so urban complexes are designed and built 'fully grown' as stand-alone projects. An urban design mimicry of the rainforest would involve development by stages and guide organic development to attain the final form and functionality planned.

The entails: (i) envisage the future city desired, (ii) identify the key development and transition phases, and (iii) build the necessary infrastructures to steer organic development towards the intended design. Heeding the wisdom in Soleri's thoughts on arcology, the city must be designed to be coherent with its environment, connecting to its natural flows and tapping from it for life-support.

C. The Urban Effect

Although miniaturisation is a central principle in arcology, it is not the goal. The purpose of minimising distance-time is to facilitate interaction, exchange, travel and transport. The resulting vibrant exchanges among a crowd is the urban effect (Soleri, 1969). A market, trading post, bazaar, city square and other structures and spaces that draws people to engage in active exchanges are examples of structures that could foster the urban effect. According to Soleri, the vitality of a city is reflected in the life and activity of its denizens; a successful city is one that facilities life processes, allowing people to pursue and attain their hopes and dreams. In contrast, a compact built structure is nothing more than a physical structure if it doesn't foster or facilitate the urban effect. In arcology, miniaturisation and complexification should be designed in a way so as to facilitate active engagement and exchanges. Similarly, it is also not about drawing in crowds per se. The focus should be on interaction and exchange among people. For instance, a battalion of soldiers, spectators in a performance, or a school assembly are also examples of crowds. However, there is little in terms of exchanges among the people, and therefore, no urban effect. As a design principle, urban design should foster exchanges in the range of services demanded by the population. For example, it would be advantageous for both the producers of food and those preparing meals to be in close proximity. Similarly, industrial activities would be more efficient and less wasteful and thus, less or non-polluting, if suppliers operate close to manufacturers. In an ecological paradigm, these linkages close ecological loops. This is a common feature in biomes, such as the rainforest.

Vertical farming in urban areas is an example of a transition towards more ecological paradigm. This is a trend in Singapore, which is highly urbanised and together its high population density, drives the trend (Seneviratne, 2012, December 12). In fact, Singapore is only slightly larger than the Brunei-Muara District in Brunei, but it has a population that is over 17 times greater. However, while most vertical farms are highly ecological, they are stand-alone agricultural units. As such, although the farms are more compact and has considerably small footprints compared with conventional farms, they do not facilitate the urban effect. This could however be altered by facilitating the development of complementary businesses within the same complex, as well as to establish connecting structures to facilitate exchanges with the public. Leung (2017) produces an interesting design of an urban arcology that centres on agriculture. However, as with most arcology projects, it is unclear if it has been realised. A relatively easy transition towards arcology would be to create livings paces in large malls. In particular, if employees and entrepreneurs are allowed to live in the mall, this could cut down travelling and traffic congestion. Adding production facilities could further reduce traffic congestion, emissions and drive the transition towards self-contained urban complexes. The focus with respect to compact design, or miniaturisation, or drawing in crowds, is really to achieve the urban effect.

D. Hyper-structure & Genius of Place

A hyper-structure should be conceptualised in similar ways as infrastructure but combined and integrated into a single structure that guides development, just as roads, water supply and power lines give rise to urban development along them. Returning to the rainforest as model and guide, new layers are created as the forest develop towards its climax stage. The canopy, for example, established a new habitat with its own energy, food and water supply. Its inhabitants would move through the layer using multiple mode of movement, from walking, running, crawling, slithering, jumping, gliding to flying. The Orang Utan, a canopy dweller, has an additional unique mode of mobility. It uses its weight to move across the tree tops by swaying tree trunks and branches so that one connects to the next (Science Daily, 2009, October 13). The urban equivalent of the rainforest canopy is a structure high above the ground that could support and sustain a population in a new way of living, with multiple modes of mobility. The interlocking canopies of individual trees functions like a bridge, but one that is not a flat, solid and rigid structure. It would be more like a thick lattice formed by interlocking branches that provide support to stand, walk, interact and on which to build structures for, e.g., rest, privacy, work, production, surveillance and management. It essentially creates real estate out of thin air, in the same way the tall

dipterocarp trees in the rainforest create new habitat high above the ground. Before the canopy layer formed, there is nothing but air.

A 'forest architect' might design hyper-structures using the layered characteristic of a rainforest to direct development upwards in new layers of real estate that are somewhat self-contained but also interconnected with the other layers as well as the surrounding environment. In the rainforest example, the emergence of the dipterocarp trees that tower over the earlier-stage vegetation created a new world that is distinctly different from the existing one below. Its height, which is over three times greater, would not block out light from the lower layers in the early transition stage. However, as the canopy becomes denser and more established, it altered the environmental conditions below, amplifying the difference between the top and ground layers. Over time, intermediate layers were developed by plants and mobile organisms climbing up the large structures to establish new layers where they could thrive and establish local systems. Epiphytes, in particular, live freely in the intermediate moist, cool spaces, drawing water and minerals directly from the surrounding, and food from organisms that interacts with them. The fig trees are particular well adapted to the vertical structure of the rainforest. They start their life high on the branches and become integrated into the canopy, taking over from the host plants, but using it for support, which they strengthened by extending their roots to the ground, inter-twining around the trunk of the host. The above are examples of genius of places, each worthy of a separate research article on biomimicry. With respect to climate resiliency, the rainforest is a biome that has developed in response to the humid tropical climate. It taps solar energy, thereby lessening heat absorbed and emitted by artificial surfaces; intercepts rainfall, mitigating against storm runoff in volume and intensity, and absorbs the energy of winds in its dense foliage while aerating its internal environment. These could be innovated and incorporated in the designs of roof, walls and floors of vertical structures to tap into environmental flows while mitigating climatic effects.

A hyper-structure modelled after the rainforest might be a raised platform-bridge that integrates an existing urban area by providing a connective space that caters to a variety of mobility and transport mode, except cars, buses or trucks. However, smaller, light vehicles could be developed for use, particularly for the less physically-able. Autonomous transporters would be favourable, and certainly not in the shape of the car, as is the way they are mostly being developed today. The latter is unnecessarily cumbersome to control and its handling is deeply entrenched in the psyche of society, which makes it difficult to sit in one and restrain the urge to take the steering wheel and step on the brake when dangerous situations are looming. Transport could be self-propelled or facilitated by transport networks within the structure. In nature, hydraulic systems are commonplace, and they should therefore be considered in place of mechanical ones that is currently the main choice. The platform would contain spaces and facilities to support a wide range of human needs, from commercial, production, entertainment, learning, recreational, and other social-cultural activities. It could support gardens, modular solar-energy units and water capture, storage and distribution system for local use. Early transitional structures would be lower, at first or second floor, and erected in the spaces between existing properties, such as along the main thoroughfare of an urban area with extensions in between commercial blocks and flats to facilitate mobility and connection with existing environment. The supporting structures, like tree trunks in the forest, could be installed in suitable unused spaces on the ground. As with tree trunks, they would have small footprint although their supporting root structure could be extensive and designed to serve other functions, such as facilitating drainage, mitigating against sedimentation, as sitting spaces, structures to organise spaces, etc. Figure 4 shows a typical shop block in Brunei and how a raised multifunctional platform could connect the urban area. It does not show details of the structures, but skeletons of trees are used to indicate their organisation and kind of open, branching patterns that such structures could be designed to have, in order to flow with environment dynamics, tapping them and ameliorating their power in the process. Solar energy could be harnessed passively for lighting and food production.

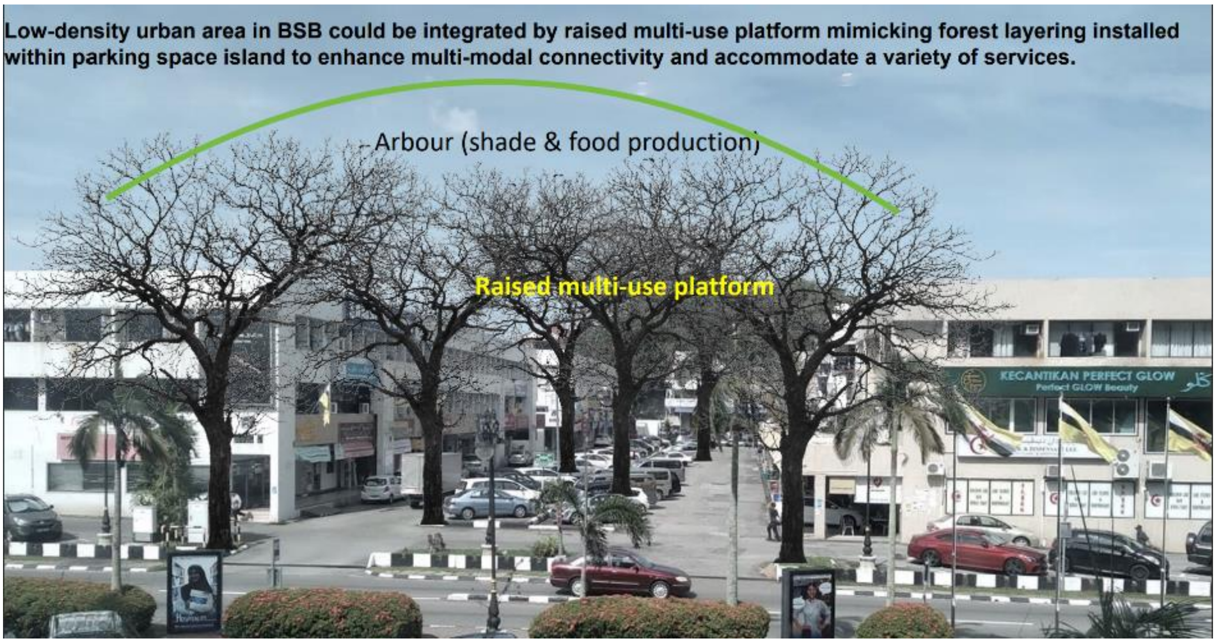


Fig. 4. Shop lot in BSB and Imagined Early-stage Hyper-structure

E. Overcoming Barriers

Arcology is a radical concept based on a paradigm that is different from the prevailing dominant one, which has guided and continue to govern policy-making, knowledge creation, and development processes. As such, it would encounter strong resistance, despite logical coherence of the concept, especially with respect to reversing the impact on climate. The barriers would have been even greater in the 1970s when technology for construction and environmental knowledge were considerably less developed. Consequently, Soleri's designs, as are many other arcology proposals, have never been built. With the emergence of biomimicry and interests catalysed largely by the efforts of Janine Benysus, biomimetic research has made great strides in unlocking some of nature's genius. Asknature is a site with a compendium of such research, including innovations in architecture and building materials. The biomimicry approach is to always ask, "how would nature deal with it?", in this case, regarding barriers. It is evident that nature, with the exception of catastrophic events, do not break down man-made physical barriers. Instead, both living and non-living elements grown on them, overwhelming the entire feature over time, when they also begin to break it down slowly, penetrating into the structure little by little, weakening it in the process. Striking visual examples are common in the tropical environment. The ancient ruins of Angkor Thom in Cambodia, is an example where fig trees could be seen growing on it with their roots prying apart the stone beneath.

If we were to mimic nature, then the best way to reverse the current unsustainable development paradigm would be to (a) build on/over the existing structures, without disturbing them, and (b) allow for organic processes to effect the transformation slowly over time. The arterial arcology concept could provide a way forward (Soleri at al., 2011). It proposes developing dense self-contained lean liner cities over major transit routes, enclosing them and drawing development towards it, thus freeing the surrounding area for recolonisation by nature over time. The concept and approach could be applied to the city of BSB in Brunei. The BSB development master plan (DMP) aims to transform the capital into a sustainable city with vibrant economy and which conserves natural and cultural heritage, by 2035 (HOK International, 2010). The plan identified Sungai Kedayan, the main river that flows through the city, and its main tributary, Sungai Gadong/Manglait, as the main ecological artery of the city. The river would also be part of the multi-mode transport network, which includes a light rail transit (LRT) system running roughly along the same lines as the rivers. Figure 5 shows a part of the BSB DMP, where integrating the two main commercial areas of Gadong and Kiulap is proposed. Presently, there has been no effort to realise the plan and the urbanisation process continues to impact the area, damaging the riparian zone through intense storm runoff, and generating frequent flash floods. An arterial arcology type of development along this short river section would integrate the two areas and give rise to new developments along the river. If designed as a proper arcology, it should generate an urban effect and

stimulate economic and social-cultural vibrancy. Indeed, the same design could be applied along the length of the main channel, which was planned to be developed into an eco-corridor. A linear arcology, when combined with biomimicry of the most appropriate biome and species, would certainly facilitate such a development. The success of the sponge city programme in China in mitigating floods in urban area (Chen et al., 2021; Li and Zhang, 2022) attest to the wisdom of learning from nature, a justification for biomimicry.

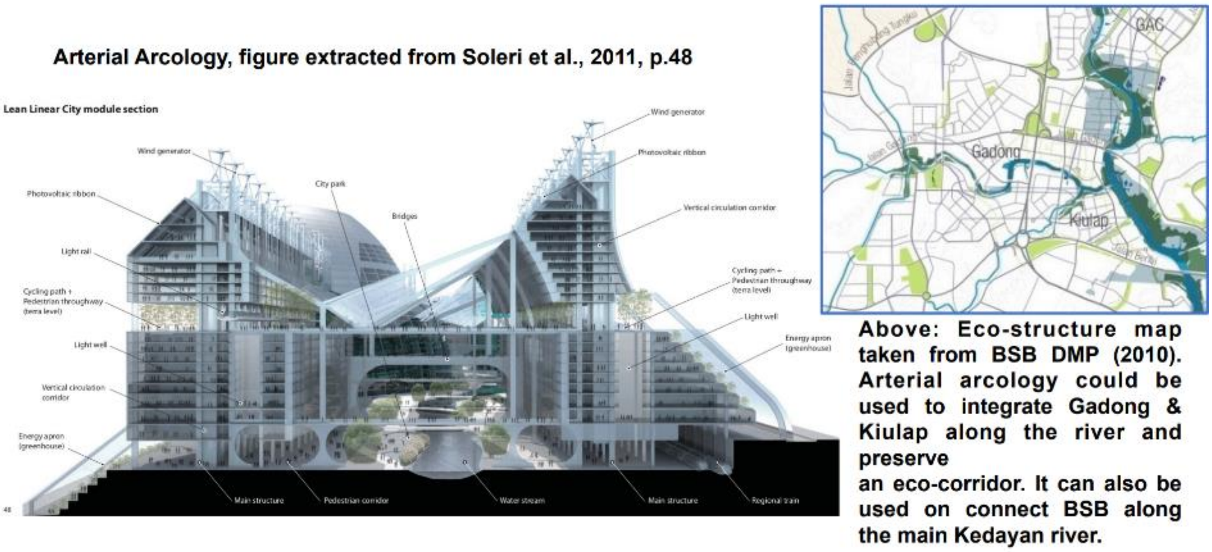


Fig. 5. BSB Development Plan and Arterial Development

IV. CONCLUSION

Things and circumstances could appear somewhat different from different perspective, particularly when the observer has a different worldview. Arcology and Biomimicry are founded on a worldview in which the surface of the planet, the human environment, exists in the Biosphere, which is a complex, living eco-system, capable of self-organisation, self-regulation and evolution. From the perspective of arcology, current development which has created ever-expanding urban sprawls that is wasteful and saps the vitality of denizens, who must routinely traverse the urban space, wasting precious time and resources in the process. Urbanisation also have real impacts on the natural environment, altering landcover and environmental flows, which shifts atmospheric and hydrological circulation patterns, resulting in greater variability, which characterise climate change. This effect of urbanisation has largely been ignored in the fight against climate change, which regards urban areas only as major emitter of CO_2 and as vulnerable to climate hazards. The rising risk of climate disasters is however due in large part to the current process/model of urban development. Arcology regard this an antithetical to natural process of increasing efficiency through miniaturisation and complexification as ecosystems develop towards their final form (maturity). It therefore views the present climate crisis to be largely caused by the model of urban development, which is founded on the 2-dimensional suburban logistical system. Climate mitigation and adaptation would not do much to reduce climate risk, even if targets were met. Instead arcology calls for a radical paradigm shift, to align with nature, adopting urban design that is coherent with the environment and the overall Biospheric system. It aligns with Biomimicry, which views nature, from individual species to communities, biomes and the biosphere, as a system in dynamic balance, and which is always tending towards it as it responds to perturbations and inputs. This is accomplished by myriad of organisms, in their diversity of forms and life strategies, the whole of which have survived and thrived over 3.8 billion years. Due to this, Biomimicry regards Nature as mentor, model and guide.

This paper presents a perspective from an Earth-as-a-complex-evolving-living-system paradigm, drawing from the central tenets of Arcology and Biomimicry on urban development and the climate crisis. It has highlighted key areas to be addressed and offer alternative urban solutions. They are summarised below.

(1) Shift urban development away from wasteful 2-dimensional expansion towards 3-dimensional integrative and compact forms. This addressed multiple environmental problems simultaneously, and could reverse the effect of climate change in the long-term.

(2) Design to achieve the urban effect, i.e., fostering and facilitating easier and greater exchanges between people, occupations, services and industries that depend on one another. This would drastically reduce waste and wastage, particularly of time and energy, and the need for transport.

(3) Invest in vertical multi-functional infrastructure, or hyper-structures, to connect the existing dispersed isolated dwellings, facilities and people, and shift development away from the ground. This could create new layers of real estate, and remove people away from the ground, away from climate hazards such as floods and forest fires. Multiple systems integrated into single large structure would make the spaces quite self-contained. Hyper-structures could be used to steer organic growth towards the desired design of the future city envisaged by planners and architects.

(4) The full range of climate type exists on Earth. In each area, the community of species that has adapted contain models of sustainable solutions embedded in their design, structure and life strategy. In Brunei-Borneo, the rainforest biome would be the most suitable for biomimicry.

(5) Finally, the transition towards a vertical future by means of hyper-structures could be developed on the very structures that drove the 2-dimesnional sprawl. Hyper-structures could be erected over major transit routes, even enclosing them and integrating them to facilitate transition to the ecological paradigm. Nature would be able to recolonise the land over time.

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